

Process and Circuit Arrangement for  
Running Time Measurement as Well as Its Use

[Verfahren und Schaltungsanordnung zur  
Laufzeitmessung sowie deren Verwendung]

Karl Griessbaum and Josef Fehrenbach

Washington, D.C.

November 2002

Translated by: Schreiber Translations, Inc.

|                               |   |  |
|-------------------------------|---|--|
| <u>Country</u>                | : | Germany  |
| <u>Document No.</u>           | : | DE 44 07 369 A1  |
| <u>Document Type</u>          | : | Patent Application Laid Open to Inspection   |
| <u>Language</u>               | : | German   |
| <u>Inventors</u>              | : | Karl Griessbaum and Josef Fehrenbach   |
| <u>Applicant</u>              | : | VEGA Grieshaber KG   |
| <u>IPC</u>                    | : | G 01 S 13/10,<br>G 01 S 15/10,<br>G 01 S 17/10,<br>G 01 F 23/28                    |
| <u>Application Date</u>       | : | March 5, 1994  |
| <u>Publication Date</u>       | : | September 14, 1995   |
| <u>Foreign Language Title</u> | : | Verfahren und Schaltungsanordnung zur<br>Laufzeitmessung sowie deren Verwendung    |
| <u>English Language Title</u> | : | Process and Circuit Arrangement for Running<br>Time Measurement as Well as Its Use |

## Specification

This invention relates to a process for running time measurement according to the features of the preamble of Claim 1 as well as a circuit arrangement for the performance of running time measurement and its use.

Processes for running time measurement are generally known and are used on a large scale for contactless distance determination and for the location of objects. The essential aspect in these pulse running time processes is the transmission of a signal of a certain frequency modulated by pulses and its reception after reflection against a target object. As a measure of the distance to be determined, one figures out the running time that to determine the distance need merely be multiplied by the corresponding propagation speed that is a function of the transmission medium. Depending on the frequency range of the modulated carrier signal of the transmission pulse, one distinguishes various forms of pulse running time measurement such as, for example, ultrasound running time measurement or microwave running time measurement or radar running time measurement.

This kind of running time measurement is used, for example, to determine filling levels in containers, measuring distances in cameras, in medical diagnosis instruments as well as for positioning tasks in automation technology.

There are various methods for extracting running time information from the existing transmission and reception signals. The simplest method involves monitoring a

---

<sup>1</sup> Numbers in the margin indicate pagination in the foreign text.

certain amplitude threshold value. When this threshold value is exceeded during the transmission phase, then, for example, a counter is started up and it is then stopped again after the reception signal has exceeded the threshold value, thus providing a measure of the desired distance. Most systems work with relatively narrow signal bandwidths and, as a result, the amplitude rise or fall in the transmission/reception pulse takes place relatively slowly over several periods of carrier oscillation, while, simultaneously, the amplitude of the reception signal can change very much depending on the target distance and the wave attenuation; therefore, considerable errors often result from the use of a firmly predetermined threshold value when it comes to running time determination.

This is why one preferably employs methods that from the electrical transmission and reception pulses cover the regenerated envelope curve and start or stop the time measurement along the rising or falling flank of this regenerated envelope curve when a detection threshold is either exceeded or not reached. If in the process the amplitude value of the detection threshold is kept in a fixed ratio with respect to the maximum of the regenerated envelope curve that belongs to the flank, then the above-described problem can be solved in case of oscillating reception amplitude.

But there is one problem connected with this method: It consists of a comparatively slow flank rise of the regenerated envelope curve due to the desired small system bandwidth. As a result of the slow flank rise or slow flank drop of the regenerated envelope curve, one gets some slight interference signals, for example, in the form of noise that immediately turn up as measurement errors on the flank of the regenerated envelope curve in that they shift the moment at which the detection

threshold is exceeded. One way of using those signal portions for more exact running time determination that have a higher frequency than the modulation frequency of the transmitted and received pulses, assuming constantly small system bandwidths, is to use, in addition, the carrier oscillation whose frequency is regularly higher than the amplitude modulation frequency by a multiple.

This kind of pulse running time measurement method that also displays the features of Patent Claim 1 is known from EP 0 324 731 B1. In the process for running time measurement described there, one first of all acquires the start of the declining side of the regenerated envelope curve in order to define a reference moment. As reference point, one uses here the first apex value of the pulse-modulated pulse that occurs after the maximum of the regenerated envelope curve. By means of this reference point in time, one finds that the running time to be determined is roughly predetermined at a predetermined point in time. It is furthermore provided that one acquire the occurrence of the first zero passage after this reference moment in order exactly to determine the running time. To the initially only roughly predetermined running time, one therefore adds the time span between the reference moment and the appearance of the zero passage. If as predetermined moment one selects the first zero passage of a transmission pulse after the first apex value in the declining side of the regenerated envelope curve of the transmission pulse, then one can measure the running time or the distance exactly.

This means that EP 0 324 731 B1 is based on the described process for running time measurement that acquires a zero passage of the carrier oscillation of the pulse-modulated pulse that beforehand was approximately restricted in terms of time. The

measurement accuracy during running time measurement can be increased by means of this method.

But it turned out that these known methods lead to erroneous running time measurements when the zero passage to be analyzed is falsified by interference signals such as, for example, noise or by interference echo signals that occur during distance measurement or that it cannot be detected at all any longer.

The object of this invention therefore was to provide a process for running time measurement that would also make use of the carrier oscillation of the pulse-modulated pulse, although then providing only a high degree of measurement accuracy when the zero passages of the carrier oscillation can no longer be detected or can no longer be detected exactly due to interference signals. Moreover, the idea was to provide a circuit arrangement for the implementation of such a process and a practical use for such a running time measurement.

This problem is solved for the process involved by the features of Claim 1.

The invention thus essentially is based on using both the amplitude information of the pulse-modulated pulse and the latter's phase information. In the invention-based process for running time measurement between a predetermined point in time and a pulse that is pulse modulated with a carrier frequency signal similar to the state of the art, one first of all approximately predetermines the running time and then one figures out the exact running time of the correction value to be considered. In contrast to known running time measurements, however, one acquires not just a single zero passage of the pulse but one measures the phase angle of the pulse and one determines the correct value according to the invention from a fraction of the carrier

frequency of the carrier frequency signal that was determined by means of the measured phase angle.

/3

This invention-based process is basically suitable for determining the running time of a pulse-modulated pulse at a predetermined zero moment; nevertheless, the invention-based process is best suitable for determining the running time between two pulse-modulated pulses such as they occur in conjunction with distance measurement. For this purpose, the transmission pulse that is pulse modulated with a carrier signal that has the carrier frequency is applied upon a measurement distance via a coupling device, for example, an antenna. The transmission pulse that is reflected against a target object reaches a reception device as a reception pulse in terms of its amplitude due to the transmission channels in a rather attenuated manner and with a time delay. First of all, one predetermines the running time in any desired fashion somewhat approximately, preferably at  $\pm \frac{1}{4}\lambda_T$  of the carrier frequency and then one determines the correction value that must also be considered to get the exact running time. To determine this correction value, one determines the phase angles of both pulses and one calculates a phase difference angle from the two phase angles. The correction value is finally determined from a fraction of the carrier frequency that is determined by the phase difference angle.

As a further development of the invention, the initially rough predetermination of the running time is done on the basis of a regenerated envelope curve detection of the pulse or pulses where, for the purpose of detecting the regenerated envelope curve, the pulse is rectified in the known manner and is supplied to a regenerated envelope curve analysis circuit.

Moreover, the following is provided according to the invention: To analyze the regenerated envelope curve, one performs a quadrature demodulation that can also be used in conjunction with phase angle acquisition. For the purpose of regenerated envelope curve detection, one performs a digital maximum search of the pulse in that the pulse is subjected to a quadrature demodulation where the maximum is determined by the sum of the squares of the  $0^\circ$  output signals and the  $90^\circ$  signals that result during quadrature demodulation. The maximum value is calculated in a practical manner then by means of a microcomputer. For this purpose, one merely need enter in suitable memories the previously digitally entered output signals of the quadrature demodulation for the pulse for one measurement cycle. In that way, one can determine the necessary rough interval between the transmission pulse and the reception pulse by simple quadrature demodulation.

The phase angle that is to be determined for the pulse-modulated pulse that is to be analyzed can be determined in any way or fashion; still it proved practical to measure the phase angle of a pulse over the entire pulse length and then to average the data. In that way, one can further improve the measurement accuracy.

As a further development of the invention to determine the phase angle, there is provided a quadrature demodulation of the pulse to be analyzed with subsequent low-pass filtration where, for the quadrature demodulation, one selects reference carrier signals that precisely display the carrier frequency of the modulated pulse. The wanted phase angle is determined in this quadrature demodulation from an arc tangent formation of the quotient of the  $0^\circ$  output signals and the  $90^\circ$  output signals that are



regenerated during quadrature demodulation and low-pass filtration. The high frequency portions that are regenerated during quadrature demodulation are suppressed by means of low-pass filtration so that for the duration of the pulses, a direct voltage is available at the output side whose amplitude only depends on the phase shift between the carrier oscillation of the pulse and the reference carrier signal of the quadrature demodulation.

According to the invention, the frequencies of the reference carrier signal of the quadrature demodulation and of the carrier signal of the pulse are equal. For this purpose, for example, one can provide a common oscillator device from whose output signal one can derive both the carrier signal of the pulse or pulses and the reference carrier signals for quadrature demodulation. In that way, one can make sure that the frequency of the carrier signal of the pulses and the frequency of the two reference carrier signals used for mixing during quadrature demodulation will be precisely equal. By using a common oscillator device, one can moreover make sure that the phase position of the two reference carrier signals of quadrature demodulation will remain equal for all measurement cycles with relation to a zero point.

An increase in the signal sensitivity of running time measurement according to the invention results from the following: The  $0^\circ$  output signals as well as the  $90^\circ$  output signals of several successive measurement cycles are averaged. Both the phase information and the amplitude information of the echo signal to be analyzed are preserved by virtue of this curve family averaging or integration of the two output signals in each case separately by themselves. A subsequent regenerated envelope curve formation according to the relationship:

$$\sqrt{I^2 + Q^2}$$

over the entire measurement cycle -- where Q designates the 0° output signal and I designates the 90° output signal of the quadrature demodulation -- leads to the known regenerated envelope curve echo signal which, however, compared to an echo signal obtained by means of customary regenerated envelope curve formation such as, for example, two-way rectification, displays a higher signal-to-noise interval so that echoes with a very small amplitude are more easily detected. Compared to a curve family averaging or integration of the regenerated envelope curve obtained, for example, by two-way rectification, which also brings about an increase in the signal-to-noise interval, the gain in terms of signal sensitivity here is definitely higher by virtue of the curve families averaging of 0° output signal and 90° output signal separately as well as the conclusive regenerated envelope curve determination according to the mentioned relationship, assuming an equal number of averaged measurement cycles; this is so because with the help of the invention-based process, the phase information of the echo signal to be analyzed by means of quadrature demodulation is also preserved for the formation of the average value.

The invention-based process for running time measurement can advantageously be used for distance measurement and especially for filling level measurement in containers where a pulse-modulated transmission pulse is transmitted into the interior of a container and after reflection against a target object is received as reception pulse or as echo pulse in a reception unit. The running time between the transmission pulse and the reception pulse, determined exactly according to the invention-based process, is

multiplied for the purpose of determining the system by a predetermined propagation speed that is a function of the transmission medium. Exact distance measurement is possible by exactly acquiring the running time between both pulses. /4

Finally, the invention-based process can advantageously also be used for distance measurement when interference echoes occur. According to the invention, an interference echo signal with amplitude, distance and phase values is stored, and from a received echo pulse, one detects the latter's regenerated envelope curve and phase angle. The actual useful echo pulse can be reconstructed in a simple manner by comparing the previously known interference echo signal and the received echo pulse.

In that way, the invention-based process can advantageously be used in conjunction with pulse running time systems whose fields of practical application make the appearance of interference echoes probable. This particularly applies to filling level measurement in containers where, along with the useful echo stemming from the filling material surface, there can also appear numerous other reflections that, for example, are due to struts or other accessories arranged in the interior of the container. To be able to make a clear differentiation between the useful echo pulse and the interference echo pulse, one therefore -- with the container empty -- records any existing interference echoes and one stores them with amplitude and distance values. A comparison between a random received echo profile with the container filled and the stored interference echo information then permits the identification of the interference sources and makes it easier to find the useful echo pulse.

According to the invention, both the amplitude information and the phase information of the received echo pulse are determined, and as established, the

amplitude information and the phase information of the interference echo are known; therefore, from the received echo signal, one can readily draw conclusions as to the amplitude and phase angle of the useful echo pulse even when the interference echo and the useful echo are mutually superposed on top of each other in part.

Claim 12 describes an invention-based circuit arrangement for the performance of the process for running time measurement.

Further developments of this circuit arrangement are given in Subclaims 13 to 18.

The invention-based circuit arrangement consequently displays a transmission and reception device for sending and receiving pulses that are pulse-modulated with an identical carrier frequency as well as a regenerated envelope curve analysis device for the purpose of determining the regenerated envelope curves of the pulses. Moreover, there is provided one each quadrature demodulator in order to generate in each case a  $0^\circ$  output signal or a  $90^\circ$  output signal from the pulses where the quadrature modulator can be operated with the carrier frequency of the pulse-modulated pulses. From the maximums of the regenerated envelope curves of both pulses, an analysis circuit first of all develops a measure for the predetermined running time between both pulses and generates the correction value to be considered for the running time from the  $0^\circ$  output signals and the  $90^\circ$  output signals.

To determine the distance between two pulses, the analysis circuit has a device that is used to calculate the distance to the target objective from the determined running time considering a predetermined propagation speed of the pulses.

The invention and its advantages will be explained in greater detail below in conjunction with three figures.

Figure 1 is a time diagram of a pulse-modulated pulse of a running time measurement instrument to explain the invention-based process.

Figure 2 is a circuit arrangement for the performance of the running time or distance measurement according to the invention in a filling level measurement instrument.

Figure 3 shows signal curves for the circuit arrangement in Figure 2.

In the subsequent Figures 1 to 3, the same reference signals refer to identical parts and identical signals unless otherwise specified.

Figure 1 shows a time diagram of a reception pulse E such as the latter, for example, is received during filling level measurement in a reception device. This reception pulse E consists of a carrier frequency signal that displays a carrier frequency  $f_T$  and that additionally is amplitude-modulated by pulses where the frequency of the amplitude modulation is by a multiple less than the carrier frequency  $f_T$ . The amplitude modulation of the reception pulse E is so chosen that the reception pulse E will display a regenerated envelope curve H with initially rising and then dropping sides. In the exemplary embodiment shown in Figure 1, reception pulse E has seven local maximums M1 to M7 where the reception pulse E is symmetrical with respect to the local maximum M4. The local maximum M4 at the same time is the maximum value ME of reception pulse E.

To determine the running time  $t_1$  or the distance  $x_1$  of a predetermined point, for example, the maximum value ME of the reception pulse E at a predetermined point in

time looking at the exemplary embodiment in Figure 1, in other words, the zero point, one first of all approximately predetermines the running time or distance and one then determines a correction value that is to be considered for the exact running time or the exact distance. This correction value is determined by the phase angle of the particular point of reception pulse E and from a fragment determined by the phase angle of the carrier frequency for the running time and from a fraction determined by the phase angle of the carrier wavelength  $\lambda_T$  for the distance to be determined.

The term "phase" here means the rotation of the phase indicator of a certain point of the carrier oscillation of the reception pulse E related to a fixed point in time or a fixed phase point at the start of each measurement, here specifically the zero point. A phase angle change of  $360^\circ$  here corresponds to a total path change by a carrier wavelength  $\lambda_T$  or a total running time change by  $1/f_T$ . After one rotation, in other words, after  $360^\circ$ , the phase angle is repeated; therefore, there is total unambiguity between phase angle and running time or between the distance to be determined only over those  $360^\circ$  or within a distance of  $\lambda_T$ . The running time  $t$  of a certain point inside reception signal E related to the zero point is determined accordingly from the sum of an integral number  $k$  of the reciprocal value of the carrier frequency and a fraction of this reciprocal value of the carrier frequency  $f_T$  that is determined by the phase angle  $\Phi$ . The running time can be calculated according to the following formula: /5

$$t = k/f_T + \Phi/(360^\circ \cdot f_T).$$

The distance  $x$  of a certain point inside reception pulse E related to the zero point, on the other hand, is calculated from the sum of a whole number  $k$  of wavelengths

$\lambda_T$  and a fraction of this wavelength determined by the phase angle  $\Phi$  where, in case of filling level measurement devices, one must also keep in mind that a transmitted pulse is first of all sent to the target object, that it is reflected there and that it is sent back to the reception device so that one must consider the double distance as a kind of round trip and one must therefore use a multiplication factor of 0.5 during distance measurement. The reflector distance in such a filling level measurement system can accordingly be calculated from the following:

$$x = 0.5(k \cdot \lambda_T + \Phi \cdot \lambda_T/360^\circ).$$

As shown clearly in Figure 1, the running time  $t_1$  or the distance  $x_1$  of each point in the reception pulse E can be determined according to the following formulas via the number  $k$  and the phase angle  $\Phi$ .

All points in the reception signal E at a distance from a wavelength  $\lambda_T$  have the same phase angle  $\Phi$ ; there, for each group of points in the interval of one wavelength  $\lambda_T$ , one can determine the phase angle of that group from a single point. As a group of points, for example, one can select all zero passages of the reception pulse E with positive rise or all local maxima M1 to M7. The choice of the group of points that are supposed to represent their phase angle  $\Phi$  by way of substitute as phase angle  $\Phi$  of the total pulse is random. The group of local maxima M1 to M7 was chosen in the exemplary embodiment in Figure 1. In the example illustrated, all points of that group have the phase angle  $\Phi = 90^\circ$  so that according to this definition this phase angle can act as a surrogate, so to speak, for the entire reception pulse E.

To determine the running time or distance of the maximum value ME of the reception pulse with respect to the zero point, one must, in addition to the phase angle of that point, only determine the integral number share  $k$  of wavelengths  $\lambda_T$  or of reciprocal values of the carrier frequency  $f_T$  between the zero point and that point.

According to the invention, one first of all somewhat predetermines the running time or distance of the particular point to the zero point. To determine the multiplier  $k$ , it suffices to have a distance measurement accuracy within the error limits of  $-\lambda_T/4$  to  $+\lambda_T/4$  or an accuracy for the running time measurement within the error limits  $-0.25/f_T$  to  $+0.25/f_T$ . Such an approximate determination of the running time or the distance, for example, is possible by means of an analysis process with a detection threshold for the sides of the regenerated envelope curve  $H$  of the reception pulse  $E$ . In the case at hand, this rough determination of the running time or distance of the maximum value ME of reception pulse  $E$  can be handled in a simple manner by forming the average value of two distance values that result when a detection threshold is exceeded or not reached because reception pulse  $E$  is symmetrical as presumed. By adding phase angle  $\Phi$  of the reception pulse  $E$ , the running time or distance, thus determined roughly in a preliminary manner, can be corrected to get the exact value. Due to the mentioned allowed error, however, one must distinguish between the following cases after determining the integral number share  $k$ :

for

$$-\lambda_T/4 < \frac{1}{2}(g \cdot \lambda_T + \Phi \cdot \lambda_T/360^\circ) - x_v \leq \lambda_T/4$$

there now applies  $k = g$ ,



for

$$\lambda_T/4 < 1/2(g \cdot \lambda_T + \Phi \cdot \lambda_T/360^\circ) - x_v \leq \lambda_T/2$$

there now applies  $k = g - 1$ ,

for

$$-\lambda_T/2 < 1/2(g \cdot \lambda_T + \Phi \cdot \lambda_T/360^\circ) - x_v \leq \lambda_T/4$$

there now applies  $k = g + 1$ , where  $x_v$  is the roughly determined distance and  $g$  is the integral portion of wavelengths  $\lambda_T$  within the roughly determined distance  $x_v$ .

The exact distance  $x_G$  is thus calculated from:

$$x_G = 1/2 \cdot (k \cdot \lambda_T + \Phi \cdot \lambda_T/360^\circ).$$

For the exact running time determination,  $\lambda_T$  must be replaced by  $1/f_T$ .

In that way, one can exactly determine for each point of the reception pulse  $E$  the running time or distance to the zero point by using the phase information found in the carrier frequency signal. Here, the measurement is not confined to the local maxima  $M1$  to  $M7$ . If one uses another definition of the phase angle, that could also, for example, involve all zero passages with positive rise or another group of remarkable points inside the reception pulse. The only essential thing here is that the corresponding point can be determined accurately, in particular, with an accuracy of up to  $\pm\lambda_T/4$  or  $\pm 0.25/f_T$ . When that is the case, then the accuracy of the measurement process depends merely on the phase measurement. /6

Although the phase angle of the particular point can be determined in the most varied ways, it proved advantageous to measure the phase angle over the entire pulse length and to average it so that the measurement accuracy of phase measurement will

be increased. For example, if one assumes a phase measurement error of  $\pm 10^\circ$ , then we get from that a measurement error for the distance in case of a filling level measurement amounting to  $\pm 1/72 \cdot \lambda_T$ .

The invention-based process for running time or distance determination between a fixed zero point and a reception signal is meaningful where a known connection exists between the zero point and the phase position of a transmission pulse. If that connection is not known, then by using the invention-based method, one can determine, both with transmission pulse and reception pulse and determination of the difference between the running time or the transmission value of the transmission pulse and the running time or the transmission value of the reception pulse, their running time difference or their interval.

The invention-based process will be explained below with reference to a concrete exemplary embodiment in conjunction with a circuit arrangement shown in Figure 2 and the pertinent signal curves in Figure 3.

The circuit arrangement in Figure 2, for example, is part of a filling level measurement device. The circuit arrangement displays a transmission and reception device 1 for sending out and receiving pulses that are pulse-modulated with an identical carrier frequency  $f_T$ . Transmission and reception device 1 is connected to a coupling element 2 that, on the one hand, is used for coupling the electrical transmission pulse to the measurement distance and for conversion into an electromagnetic wave and, on the other hand, after reflection of the transmitted wave against a reflector 3, for example, a filling material surface in a container for the reconversion of the received

electromagnetic wave into an electrical signal and thus a reception pulse. At a signal output 4 of the transmission and reception device 1, one can thus first of all tap a transmission pulse and then a reception pulse which are identical regarding their carrier frequency  $f_T$ . Of course, the amplitude of the reception pulse E is attenuated due to the attenuation of the transmission distance. Additional devices can be provided in the transmission and reception device 1 in order to amplify and possibly filter the transmission and/or reception pulse.

The time diagram a in Figure 3 shows an example of a transmission pulse that is sent out and a reception pulse that is received by the transmission and reception device 1. The transmission pulse is labeled S and the reception pulse is labeled E. As one can clearly see, transmission pulse S and reception pulse E have the same pulse-modulated carrier frequency  $f_T$  where the reception pulse E due to the transmission distance has a lower amplitude. The running time of transmission pulse S and reception pulse E is determined by the time interval of their two maximum values  $M_S$  and  $M_E$ . Using the circuit arrangement, which is to be described further, one can -- by applying the invention-based process -- exactly determine the running time  $t$  and thus the distance  $x$  between transmission pulse S and reception pulse E.

For this purpose, the arrangement shown in Figure 2 has an oscillator device 26 that supplies an oscillator output signal with an oscillator frequency of  $f_0$ . The oscillator output signal is supplied to a first divider 27 that divides the oscillator output signal by a factor  $N$  so that at the output of divider 27, there will be available a signal with a frequency of  $f_S$ , which determines a measurement cycle. Moreover, the oscillator output signal gets to another divider stage 28 that divides the oscillator output signal by a

factor  $P$ . The carrier frequency signal for pulse transmission in the transmission and reception device can be tapped at the output of divider stage 28. The carrier frequency signal has the carrier frequency  $f_T$  that is by a multiple greater than the frequency  $f_S$ . The outputs of both divider stages 27 and 28 are connected to the transmission and reception device 1.

In order approximately to predetermine the running time  $t$  or the distance  $x$  between transmission pulse  $S$  and reception pulse  $E$  and subsequent correction value determination, the circuit arrangement in Figure 2 has a regenerated envelope curve analysis device 5 and a quadrature demodulator 20 that in each case are connected on the input side with the signal output 4 of the transmission and reception device 1.

The regenerated envelope curve analysis device 5 is used to determine the regenerated envelope curves  $H$  of the transmission and reception pulses  $S$  and  $E$ . For this purpose, regenerated envelope curve analysis device 5 has on the input side a rectifier arrangement 6, for example, a two-way rectifier with series-connected low-pass 7. The output of low-pass 7 is connected to a comparator 8 that has an adjustable threshold value. Connected to the output of this comparator 8 is the cycle connection of a JK flip-flop 9 whose  $Q$ -output connection  $q$  is connected to the input of a binary counter 12. The output of comparator 8, moreover, is connected via an inverter 11 with a cycle connection of another JK flip-flop 10 whose  $Q$ -connection  $q$  is connected to another binary counter 13. The two binary counters 12, 13 in each case have a reset connection  $R$  and a cycle connection  $T$ . The reset connections  $R$  are linked to the output of the divider stage 27, while the cycle connections  $T$  are connected to the output of the oscillator device 26.

The output connections 32, 33 of the two binary counters 12, 13 are linked to an analysis circuit 14. From the maxima MS, ME of the transmission pulse S and the reception pulse E determined in the regenerated envelope curve analysis device 5, this analysis circuit 14 generates a measure for the approximately predetermined running time or distance between transmission pulse S and reception pulse E. For this purpose, analysis circuit 14 as a microcomputer 15. Microcomputer 15 also determines the correction value that is to be considered for the exact running time or the exact distance of the preliminary approximate running time or distance measurement. Analysis circuit 14 also has two analog-digital converter stages 18, 19 whose output connections are linked with one each memory 16, 17. Memories 16, 17 are linked to microcomputer 15. The analog-digital converter stages 18, 19 are in each case linked to an output connection 30, 31 of the quadrature demodulator 20. /Z

The quadrature demodulator 20 has the known structure. Quadrature demodulator 20 has a first multiplier 21 and a second multiplier 22 whose first input connection in each case is connected with the signal output 4 of the transmission and reception device 1. The second signal inputs of the two multipliers 21 and 22 are linked to the output connection of the divider stage 28 where a phase shift device 25 is arranged in front of the second input of the second multiplier 22, which device phase-shifts the output signal of the divider stage 28 by  $-90^\circ$ . The outputs of the two multipliers 21 and 22 are in each case connected via a low-pass 23, 24 with an output connection 31, 30 of the quadrature demodulator 20.

The input signal on the second input of the first multiplier 21 is labeled u and the label v is applied to the signal that is applied on the second input of the second

multiplier 22 [that is] the input signal that is phase-shifted by  $-90^\circ$ . The  $0^\circ$  output signal at output connection 31 of quadrature demodulator 20 is labeled Q and the  $90^\circ$  output signal at output connection 30 is labeled I.

The wave the circuit arrangement shown in Figure 2 works is explained clearly with reference to the signal curves a to k in Figure 3. The signal curves a to k, shown in Figure 3, are marked in Figure 2 at the occurring places.

As stated earlier, the signal curve a represents the transmission pulse S and the reception pulse E, which for this purpose appears at a time interval. Transmission and reception device 1 is triggered on coupling element 2 by a side of the signal applied at the output of divider 27 with the frequency  $f_s$  (see b in Figure 3). The regenerated envelope curve analysis circuit 5 is used to make a preliminary rough determination of the running time or distance.

By rectification and low-pass filtration of the signal applied at signal output 4, one can tap at the output of low-pass 7 of the regenerated envelope curve analysis device 5 the signal that is illustrated in the signal curve c in Figure 3, which signal is relieved of the high-frequency shares of the carrier signal. The threshold value SW, indicated by the broken line in the signal curve c, is set in comparator 8. The detection threshold SW can be predetermined in a fixed manner or can be adjusted via the control and analysis circuit 14. At the output of comparator 8, one can tap a rectangular signal whose rising sides are determined by exceeding and whose falling sides are determined by falling short of the detection threshold SW of the signal that is applied at the output of low-pass 7.

The rising sides of this rectangular signal in signal curve d trigger the JK flip-flop 9 that beforehand, just as the JK flip-flop 10 and the binary counters 12 and 13, were reset by the rising side of signal  $f_s$  at the start of pulse transmission. In the first rising side of the rectangular signal in signal curve d, the JK flip-flop 9 at its input releases the binary counter 12 and stops it during the next rising side as one can see in the signal curve. The JK flip-flop 10 and binary counter 13 work in a similar manner where, by providing the inverter 11 at the cycle input of the JK flip-flop 10, we find that it is not the rising sides of the rectangular signal that are critical but rather the latter's falling sides are decisive.

As one can see in Figure 3, moreover, from the signal curves e and f, the counting cycle is by a multiple greater than the carrier frequency  $f_T$ . It so happens that the counting cycle corresponds to the frequency of the oscillator output signal and thus the oscillator frequency  $f_0$ .

At the end of a measurement cycle that is determined by the descending side of signal curves b, binary counter 12 thus contains a number Z1 that is a measure of the interval between the front side of transmission pulse S and the front side of reception pulse E. In a similar manner, binary counter 13 contains a number Z2 that is a measure of the interval between the rear side of transmission pulse S and the rear side of reception pulse E. The counter statuses in the binary counters 12, 13 and thus the numbers Z1 and S2 stored there are not identical because the amplitudes of transmission and reception pulse S, E mostly differ. Microcomputer 15 in control and analysis 14 forms a mean value from these two counterstatuses that can be considered a measure of the interval of the maximum value MS of the transmission pulse S and the

maximum value ME of the reception pulse E. This means that one has performed the preliminarily rough determination of the distance or the running time between transmission pulse S and reception pulse E. The preliminary rough determination of the distance  $x_v$  between transmission pulse S and reception pulse E results from the following formula:

$$x_v = \frac{1}{2}(Z_1 + Z_2) \cdot \frac{1}{f_0} \cdot v \cdot \frac{1}{2},$$

where  $v$  refers to the propagation speed of the wave.

The phase angle of transmission pulse S and reception pulse E is determined furthermore for the sake of the exact running time or distance determination of the circuit arrangement illustrated in Figure 2. Here, one uses the quadrature demodulator 20. Transmission pulse S and reception pulse E are multiplied in quadrature demodulator 20 with the signals  $u$  or  $v$  and are then low-pass filtered. The signals  $u$  and  $v$  have the same frequency as the carrier signal of transmission pulse S and reception pulse E. This frequency is the carrier frequency  $f_T$ . As one can see by looking at the signal curves  $g$  and  $h$  in Figure 3, the signals  $u$  and  $v$  are rectangular signals with the carrier frequency  $f_T$ , where the signal  $v$  is phase-shifted by  $-90^\circ$  with respect to signal  $u$  due to the phase-shift arrangement 25. Transmission pulse S and reception pulse E are mixed by mixing or multiplying with the signals  $u$  or  $v$  into the intermediate frequency position zero in the two channels of quadrature demodulator 20. Low-passes 23 and 24 behind the two multipliers 21, 22 supplies the high frequency shares that are regenerated during multiplication so that for the duration of the pulses, there will be at the outputs of the two low-passes 23, 24 a direct voltage whose amplitude now depends



only on the phase shift between the corresponding signal bus S or the reception pulse E and the signal u or v. /8

The output signals at connections 30 and 31 of quadrature demodulator 20 that belong to the transmission and reception pulse S, E shown in Figure 3 are shown with reference to the signal curves i and k in Figure 3. The output signals Q and I of quadrature demodulator 20 can be calculated as follows:

$$I = a \cdot \cos \alpha$$

$$Q = a \cdot \sin \alpha.$$

By correspondingly selecting the signals u and v with regard to the zero point, one can make sure that the displayed phase angle  $\alpha$  will be equal to the above-described phase angle of transmission pulse S or reception pulse E. The proportionality constant  $a$  here depends on the parameters of the practical realization and is mostly unknown. But one can eliminate it by division because the following applies:

$$Q = a \cdot \sin \alpha$$

$$- = \frac{Q}{I} = \tan \alpha = \tan \Phi.$$

$$I = a \cdot \cos \alpha$$

The control and analysis circuit 14 can utilize this relationship. The analog output signals I and Q of the quadrature demodulator 20 are digital-converted and are deposited in the following memories 16, 17 in the analog-digital converter stages 18, 19.

In signal curves i and k in Figure 3, QS or QE designate the 0° output signals of the quadrature demodulator 20 in case of transmission or reception pulse applied on the input side and IS or IE designate the corresponding 90° output signals. By means of

division and arc tangent formation, microcomputer 15 can determine the particular wanted phase angles  $\Phi$  for transmission pulse S and reception pulse E. Here, one can get around the ambiguity of the arc tangent between  $0^\circ$  and  $360^\circ$  by including the signs of signals I and Q. Looking at the exemplary embodiment in Figure 3, one gets  $\Phi_S = 180^\circ$  for the phase angle  $\Phi_S$  of the transmission pulse S, and for the phase angle  $\Phi_E$  of the reception pulse E, one gets  $\Phi_E = 90^\circ$ .

The phase angles  $\Phi_S$  and  $\Phi_E$ , thus determined, are the result of the formation of the difference of their reciprocal phase shift  $\Phi_G$ .

$$\Phi_G = \Phi_E - \Phi_S = 270^\circ.$$

For the exact distance between transmission and reception pulses S, E, the following applies:

$$x_G = \frac{1}{2}(k \cdot \lambda_T + \Phi_G \cdot \lambda_T / 360^\circ),$$

where k is determined according to the above case differentiation.

It has thus been shown that the circuit arrangement presented here facilitates highly accurate running time and distance measurement where, first of all, one predetermines the running time or distance and then determines a correction value that considers the exact running time or distance. For the correction value, one measures the phase angle of the pulse or pulses and the correction value is determined from a fraction set by the phase angle of the carrier frequency or the carrier wavelength. By using quadrature demodulation for phase angle determination, one can furthermore make sure that the phase angle of the pulse will be measured over the entire pulse length and will thus be averaged out. That facilitates highly accurate measurement.

## List of References

- 1 Transmission and reception device
- 2 Coupling element
- 3 Reflector
- 4 Signal output
- 5 Regenerated envelope curve analysis device
- 6 Rectifier arrangement
- 7 Low-pass
- 8 Comparator
- 9 JK flip-flop
- 10 JK flip-flop
- 11 Inverter
- 12 Counter
- 13 Counter
- 14 Control and analysis circuit
- 15 Microcomputer
- 16 Memory
- 17 Memory
- 18 Analog/Digital converter stage
- 19 Analog/Digital converter stage
- 20 Quadrature demodulator

/9

|                |   |
|----------------|---|
| 21             | First multiplier                        |
| 22             | Second multiplier                       |
| 23             | Low-pass device                         |
| 24             | Low-pass device                         |
| 25             | Phase shift arrangement                 |
| 26             | Oscillator device                       |
| 27             | Divider stage                           |
| 28             | Divider stage                           |
| 30             | Output                                  |
| 31             | Output                                  |
| 32             | Output connection                       |
| 33             | Output connection                       |
| t <sub>1</sub> | Time span                               |
| t              | Time                                    |
| Z <sub>1</sub> | First counter status                    |
| Z <sub>2</sub> | Second counter status                   |
| K              | Correction value                        |
| E              | Reception pulse                         |
| QE             | 0° output signal of reception pulse     |
| QS             | 0° output signal of transmission pulse  |
| IE             | 90° output signal of reception pulse    |
| IS             | 90° output signal of transmission pulse |

|             |                            |
|-------------|----------------------------|
| H           | Regenerated envelope curve |
| I           | 90° output signal          |
| M           | Maximum                    |
| N           | Factor                     |
| Q           | 0° output signal           |
| P           | Factor                     |
| S           | Transmission pulse         |
| R           | Reset connection           |
| T           | Cycle connection           |
| SW          | Threshold value            |
| $f_T$       | Carrier frequency          |
| $f_S$       | Frequency                  |
| $f_O$       | Oscillator frequency       |
| q           | Q connection               |
| u           | Signal                     |
| v           | Signal                     |
| x, xl       | Distance                   |
| $\lambda_T$ | Wavelength                 |
| $\Phi_E$    | Phase angle                |
| $\Phi_S$    | Phase angle                |
| $\Phi$      | Phase angle                |

## Claims

1. Process for running time measurement between a predetermined point in time and a pulse (E) that is pulse-modulated with a carrier signal that has a carrier frequency ( $f_T$ ) where, first of all, one approximately predetermines the running time and then determines a correction value (K) that considers the exact running time, characterized in that the phase angle ( $\Phi$ ) of pulse (E) is measured and that the correction value (K) is determined from a fraction of carrier frequency ( $f_T$ ) determined by the phase angle ( $\Phi$ ).

2. Process according to Claim 1, characterized in that the predetermined point in time is determined by a prior pulse (S) that is pulse-modulated with the same carrier signal, that the phase angles ( $\Phi_S$ ,  $\Phi_E$ ) of both pulses (S, E) are determined, that from the two phase angles ( $\Phi_S$ ,  $\Phi_E$ ), one forms a phase difference angle ( $\Phi_S - \Phi_E$ ) and that the correction value (K) is determined from a fraction set by the phase difference angle ( $\Phi_S - \Phi_E$ ) of the carrier frequency ( $f_T$ ).

3. Process according to Claim 1 or 2, characterized in that the phase angle ( $\Phi_S$ ,  $\Phi_E$ ) of a pulse (S, E) is measured over the entire pulse length and is averaged out.

4. Process according to one of Claims 1 to 3, characterized in that the running time is first of all precisely predetermined for  $\pm 4/f_T$ .

5. Process according to one of Claims 1 to 4, characterized in that the running time is first of all approximately predetermined on the basis of a regenerated envelope curve detection of the pulse or pulses (S, E).

6. Process according to Claim 5, characterized in that for regenerated envelope curve detection, one performs a digital maximum search of the pulse (S, E) in that the pulse (S, E) is subjected to a quadrature demodulation and that the maximum (MS, ME)

is determined by the sum of the squares of the 0° output signal (Q) and 90° output signal (I) of quadrature

demodulation. /10

7. Process according to one of Claims 1 to 6, characterized in that a pulse (S, E) for the purpose of determining its phase angle ( $\Phi_S$ ,  $\Phi_E$ ) is subjected to a quadrature demodulation with subsequent low-pass filtration, where for the quadrature demodulation, one selects reference carrier signals that have the carrier frequency ( $f_T$ ) and that the phase angle ( $\Phi_S$ ,  $\Phi_E$ ) is determined from an arc tangent formation of the quotient of the 0° output signal (Q) and the 90° output signal (I) developing during quadrature demodulation and low-pass filtration.

8. Process according to one of Claims 1 to 7, characterized in that from a common oscillator device (26) by division, one derives both the carrier signal with the carrier frequency ( $f_T$ ) of the pulse (E) or of the pulses (S, E) as well as the reference carrier signals for quadrature demodulation.

9. Process according to one of Claims 1 to 8, characterized in that in several successive measurement cycles, the 0° output signals (Q) as well as the 90° output signals (I) formed by means of quadrature demodulation are curve-family averaged among each other and that this is followed by regenerated envelope curve formation according to the relationship:

$$\sqrt{I^2 + Q^2}$$

where for regenerated envelope curve formation, one uses the average values of the 0° output signal (Q) and of the 90° output signal (I).

10. Use of the process according to one of Claims 1 to 9 for distance measurement, in particular, for measuring the filling level in containers, where the preceding pulse (S) is a transmission pulse transmitted into the container and where the further pulse (E) is an echo pulse and where the determined running time between the two pulses (S, E) is multiplied by a predetermined propagation speed to determine the distance.

11. Use according to Claim 10, where at least one interference echo signal is stored with amplitude, distance and phase values and where, from the received echo pulse, a useful echo pulse is reconstructed with detected regenerated envelope curve values and phase angle ( $\Phi_E$ ).

12. Circuit arrangement for the performance of the process according to one of Claims 1 to 10, characterized by the following features:

- a transmission and reception device (1) for the purpose of transmitting and receiving pulses that are pulse-modulated with identical carrier frequency ( $f_T$ );
- a regenerated envelope curve analysis device (5) to determine the regenerated envelope curves (H) of the pulses (S, E);
- a quadrature demodulator (20) in order from the pulses (S, E) in each case to generate a  $0^\circ$  output signal (K) or a  $90^\circ$  output signal (I), where the quadrature demodulator (20) can be operated with reference carrier signals that have a carrier frequency of ( $f_T$ );
- an analysis circuit (14) in order to generate a measure from the maximums (MS, ME) of the regenerated envelope curves (H) of both



pulses (S, E) for the approximately predetermined running time between the two pulses (S, E) and to form the correction value (K) for the running time from the 0° output signal (Q) and the 90° output signal (I).

13. Circuit arrangement according to Claim 12, characterized in that the analysis circuit (14) has a device in order to calculate a distance between the two pulses (S, E) from the determinable running time considering a predetermined propagation speed of the pulses (S, E).

14. Circuit arrangement according to Claim 12 or 13, characterized in that there is provided an oscillator device (26) that is possibly connected via divider stages (27, 28) with the transmission and reception device (1) and the quadrature demodulator (20).

15. Circuit arrangement according to one of Claims 12 to 14, characterized in that the quadrature demodulator (20) is provided on the output side with one each low-pass device (23, 24).

16. Circuit arrangement according to one of Claims 12 to 15, characterized in that the analysis circuit (14) has a microcomputer (15), that microcomputer (15) is linked to regenerated envelope curve analysis device (5) and to a storage device (16, 17) and that an analog-digital converter device (18, 19) is connected between memory device (16, 17) and quadrature demodulator (20).

17. Circuit arrangement according to one of Claims 12 to 16, characterized in that the regenerated envelope curve analysis device (5) on the input side has a rectifier arrangement (6) with series-connected low-pass (7) and comparator (8), that connected to the output of comparator (8), there are two flip-flops (9, 10) with in each case following counter (12, 13), where in front of one of these two flip-flops (9, 10), there is

arranged an inverter (11) and where the output connections (32, 33) of the counters (12, 13) are connected with the analysis circuit (14).

18. Circuit arrangement according to Claim 17, characterized in that the flip-flops (9, 10) are JK flip-flops where a cycle connection of a first flip-flop (9) is directly connected with comparator (8) and a cycle connection of the second flip-flop (10) is connected to the comparator (8) via inverter (11) and where the Q output connections (q) of the JK flip-flops (9, 10) in each case are connected to one of the counters (12, 13).

19. Switching arrangement according to one of Claims 12 to 16, characterized in that the regenerated envelope curve analysis device (5) is a part of the analysis circuit (14) and that the regenerated envelope curve values are calculated from the 0° and 90° output signal values (I, Q) stored in the memory device (16, 17) of the analysis circuit (14) with the help of microcomputer (15) according to the following relationship:

$$\sqrt{I^2 + Q^2}.$$

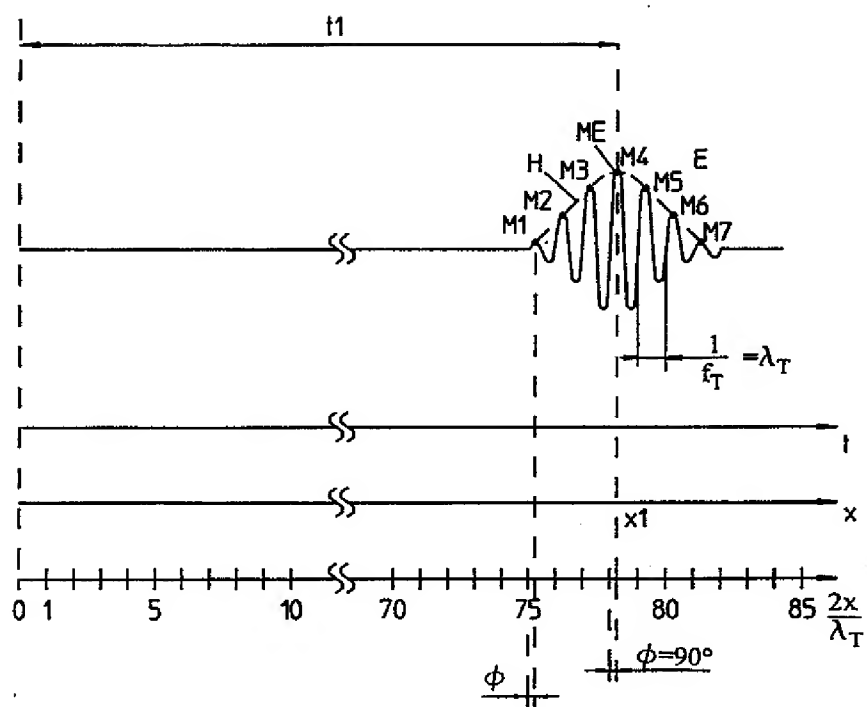


Fig. 1

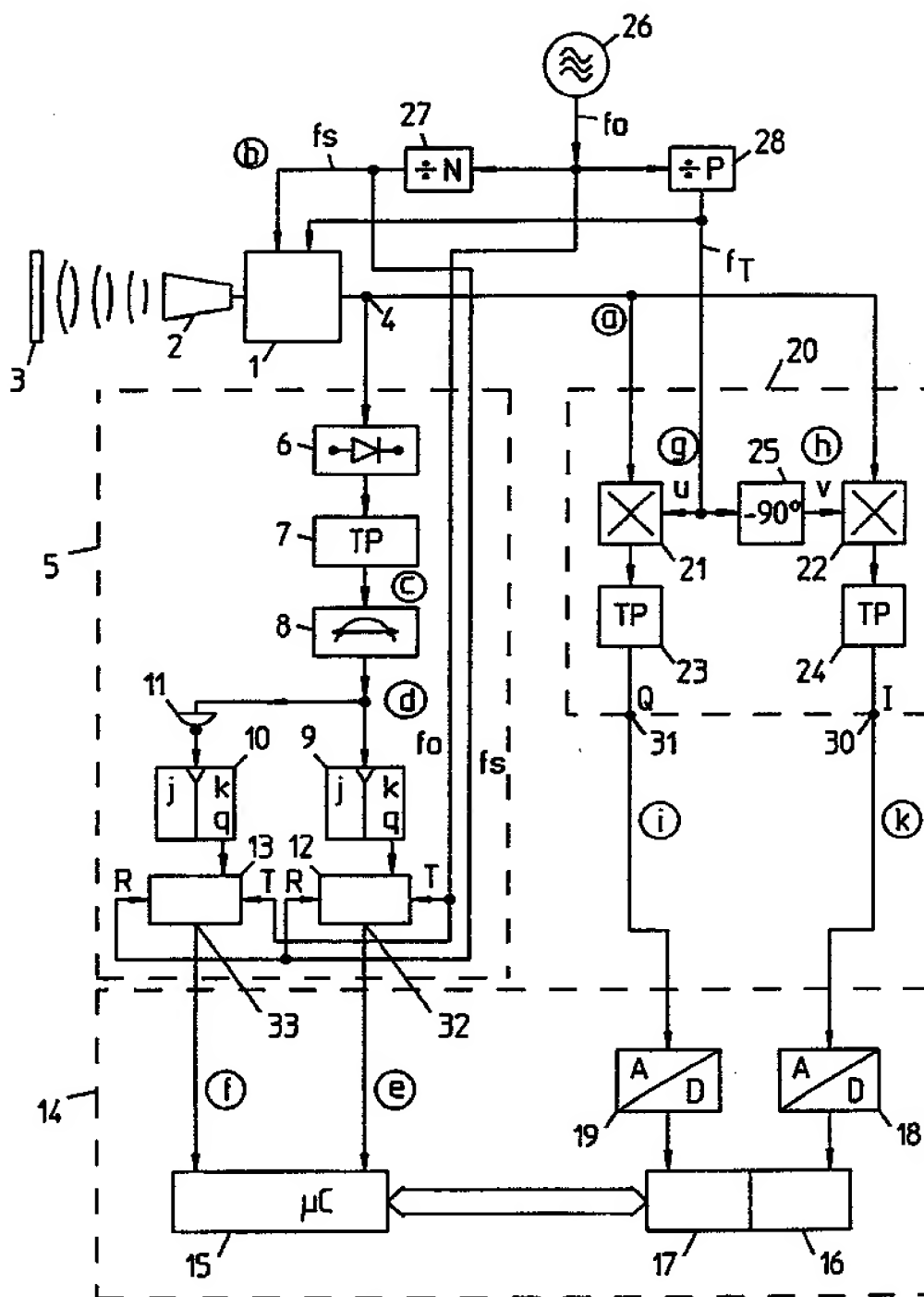


Fig. 2



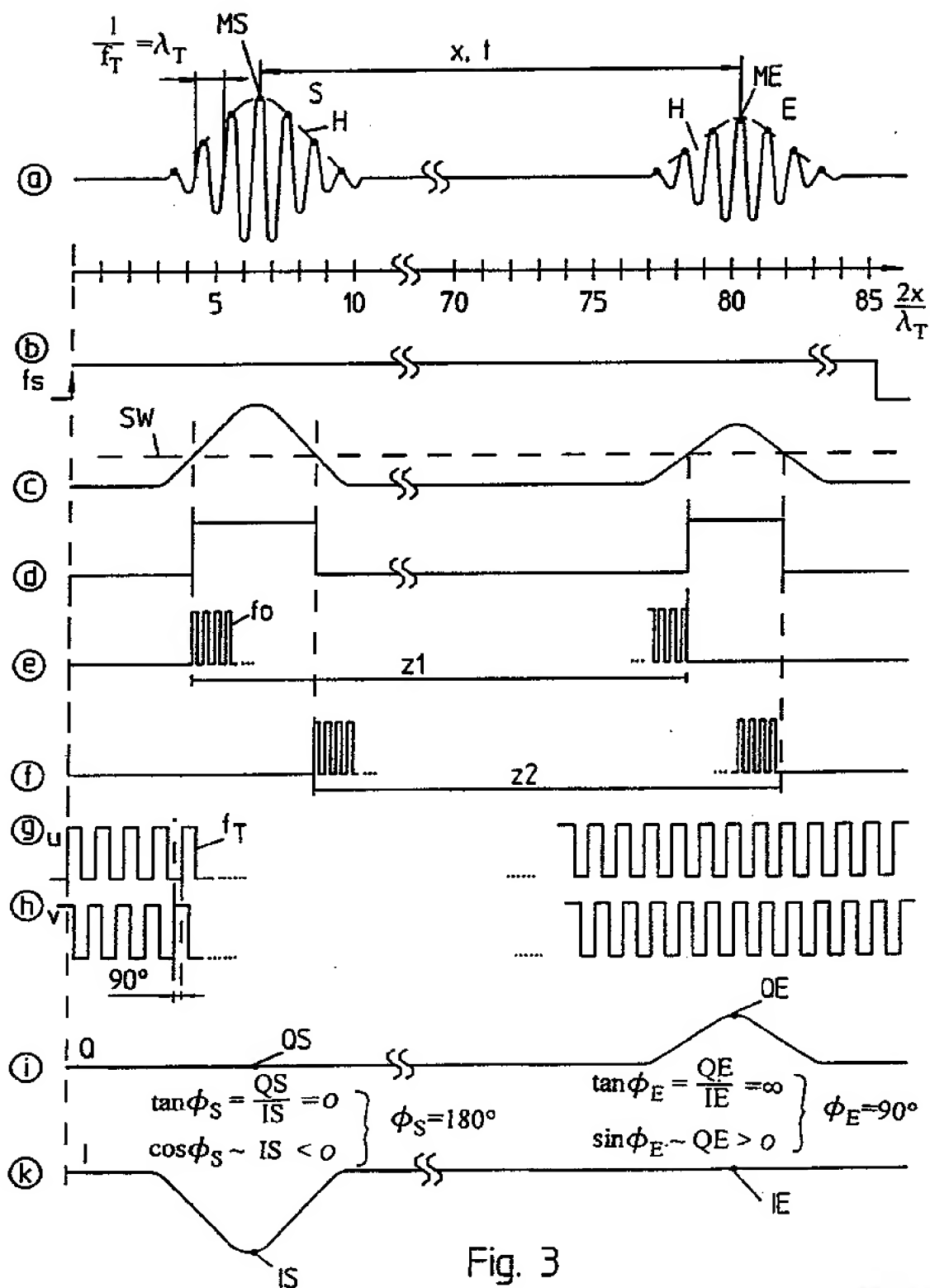


Fig. 3

508 037/87

